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(54) **Method of making uniformly sized liposomes and liposomes so made.**

(57) A composition whereby pharmaceutically active ingredients such as the bis-anthracyclines disclosed and claimed in European Application Publication No. 0 004 467 may be effectively delivered to selected sites in a mammalian organism is made by incorporating the ingredients within uniformly sized liposomes.

Uniformly sized liposomes are made by extrusion of more or less randomly sized liposomes at high pressure through a very fine orifice.

EP 0 036 676 A1

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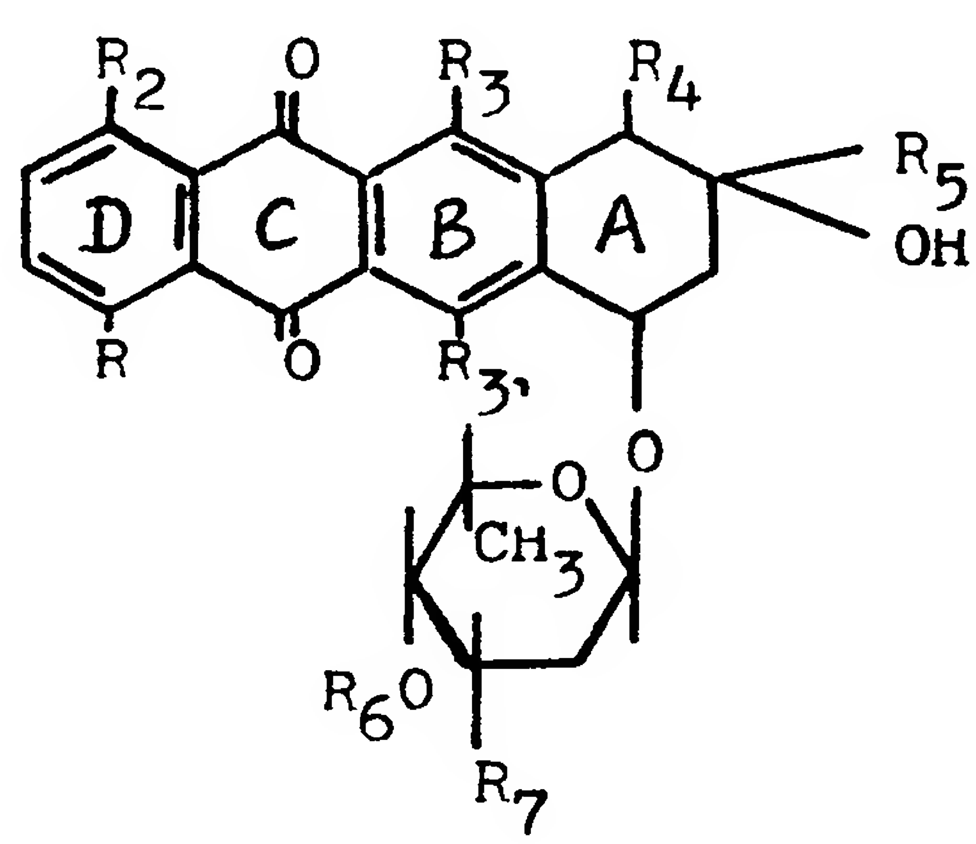
METHOD OF MAKING UNIFORMLY SIZED LIPOSOMES AND LIPOSOMES SO MADE

This invention relates to liposomes. These are used as a vehicle for administration of drugs. It is particularly (though not exclusively) concerned with the incorporation into such liposomes of bis-anthracyclines, which have utility in inhibiting DNA function and therefore as anti-cancer drugs Such compounds are disclosed and claimed in European Application 79300470.6 (Publication No. 004467) from which the present application is divided.

Anthracyclines are compounds previously isolated and studied and which have shown activity as bacterial antibiotics and anti-cancer agents in mammalian chemotherapy. Most such anthracyclines are natural products derived from the bacterial species, Actinomycetes and Streptomycetes. Generally, such anthracyclines have the structure:



wherein R_1, R_2 and R_3 are usually -H, -OH or $-OCH_3$. The R_6 substituent is normally -H or a mono-or di-saccharide; while R_7 is, most often, -OH, or a simple -amine or alkylamine. The ring structure designated "A" has a wide variation in the R_4 and R_5 substituents. R_4 may range from -H to a -carboxyl ester; while R_5 may be $-CH_2CH_3$, $-\overset{O}{\overset{\|}{C}}CH_3$, $-\overset{O}{\overset{\|}{C}}CH_2OH$, or $\overset{CH_3}{\overset{|}{C}}$=NNHCOØ. Where the R_5 substituent is $-CH_2CH_3$, the commercial products are known as Cinerubin or Aclacinomycin; where it is $-COCH_3$, the commercial products are known as Daunorubibin; where $-COCH_2OH$, as Adriamycin; and where a C=NNHCOØ, as Rubidazone. In these formulae, ϕ = phenyl.

While many anthracyclines have been produced, most exhibit low effectiveness or potency against neoplasms, or produce unacceptable side effects. On the other hand, some anthracyclines, such as the aforementioned Daunorubicin and Adriamycin find clinical use in the treatment of various types of cancer. It appears that those anthracyclines in which R_1 is -H or sometimes OH are quite toxic compared to those with $-OCH_3$. Where R_3 is a methoxy group, the anti-cancer activity appears to be less than where R_3 is the hydroxy group. In addition, most anthracyclines produce accumulative toxicity to vital tissues such as bone marrow

and heart. While over one hundred analogs are now known, most are less potent and less effective than the four or five clinically useful analogs.

It is theorized that the anthracyclines block the functions of the deoxyribonucleic acids (DNA) by insertion of their BCD aromatic ring region in betwen successive base pairs of the DNA structure. Thus it appears that the drug effectiveness relies upon the binding thereof to a site on the receptor DNA molecule and/or other receptor molecules. Some evidence suggests that the drug acts only so long as it is bound to the receptor site and is made inactive as soon as it dissociates therefrom. It also appears that if it were possible to assure that a greater number of closely related receptor sites were drug-occupied, effectiveness would be greatly enhanced. Unfortunately, there is a vanishingly small probability that two drug molecules ingested at the same time will arrive simultaneously at related receptor sites and both remain simultaneously bound thereto.

Underlying the present invention, on the other hand, is the discovery that if either drug molecule is attached to a similar drug molecule, then as it arrives at the receptor area it will increase the chance of two-receptor interactions occurring at almost the same time by an enormous factor. The further chance that both will dissociate from their respective receptor sites at the identical moment is also greatly reduced.

In addition, each time one part of the molecule begins to dissociate the attachment of the other part of the molecule will enhance the opportunity that the dissociating part will re-attach. It appears therefore that a drug with multiple receptor sites binding ability could potentially be much more potent and effective than a drug having only one receptor site binding structure. Although the drugs disclosed herein are anthracylines, this principle has obvious application to other drug classes.

In addition to the ability to effectively attach to binding sites on the cell DNA, and other receptor molecules, drug effectiveness is very much related to its toxicity against the tissues of the disease-free or normal portions of the organism. It is therefore desirable to protect the normal portions of the organism from the drug, yet at the same time, effectively direct the drug specifically against the diseased tissues of the organism. Any means of selectively directing the drug to the diseased portions while bypassing the disease-free portions of the organism will greatly benefit the effectiveness of any therapeutic methods. In addition, such method should enable the use of lower dosages relative to the weight of the organism as a whole but, yet supplies sufficient drug at the diseased

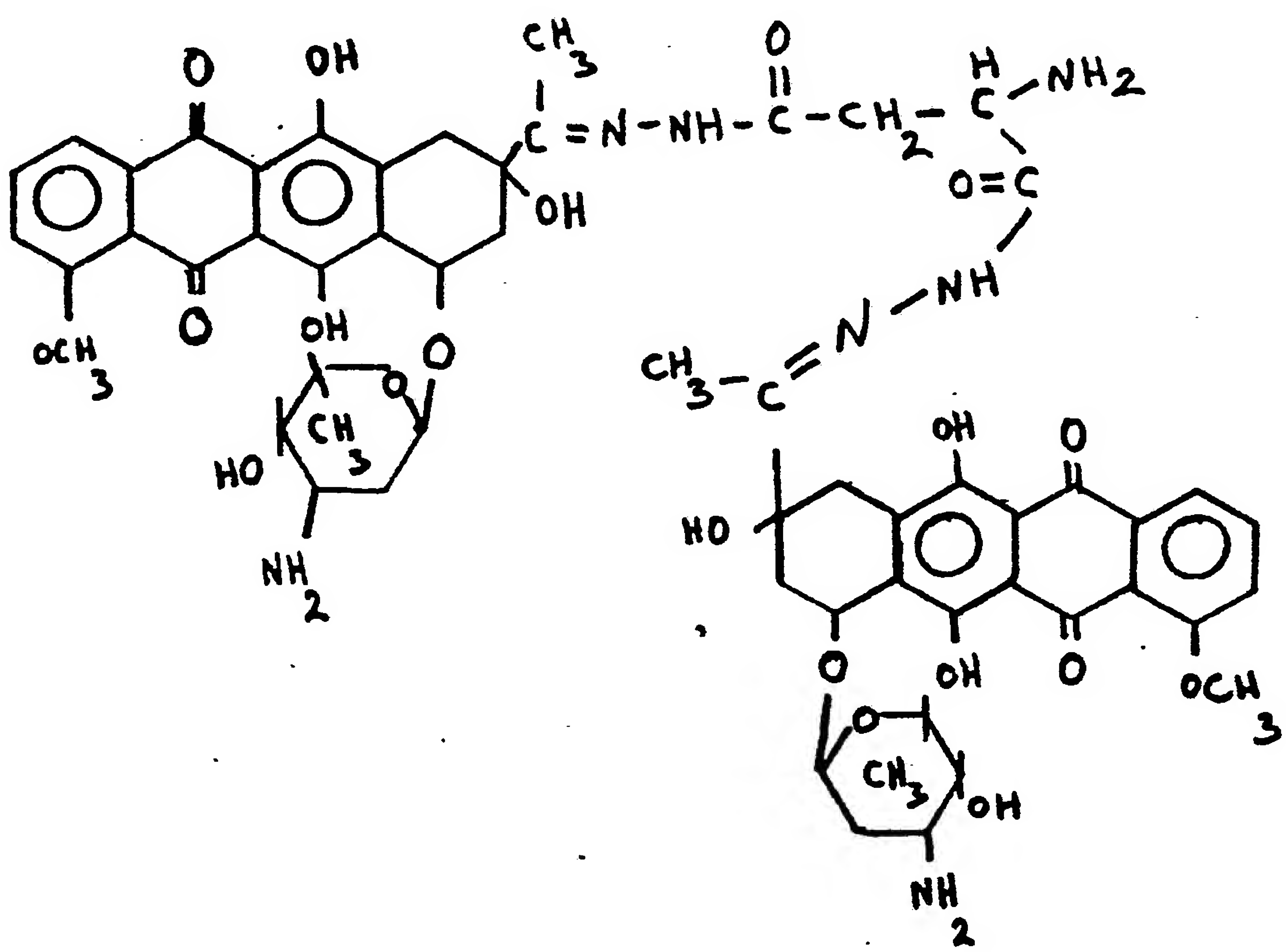
sites to produce a high level of activity against the diseased portions of the organism. Lower dosage rates combined with careful "targeting" of the drug to the diseased site will obviously greatly diminish undesired side effects to the organism.

It should be understood that while the theories expressed above may underlie the demonstrated effectiveness of the drug and treatment method disclosed hereinafter, its accuracy should in no way be taken to limit the fact that the bis-anthracyclines and liposome delivery method disclosed hereinafter truly demonstrate an improvement over previously known related drugs and methods.

Improved anthracycline compounds have been prepared. These compounds show increased effectiveness against neoplasms. In addition, a method has been devised for increasing the specificity of action of said anthracyclines against neoplasms whereby the effective dosage rate may be greatly reduced and pervasion of the drug throughout the entire organism is minimized.

More specifically, the novel compounds of the invention comprise bis-anthracyclines wherein two

anthracycline molecules are linked together to form a single molecular structure. The linkage units are derived from hydroxy-or amino-dicarboxylic acids. According to the invention, all known anthracyclines can be linked into bis-compounds; however, for the purposes of the invention, those anthracyclines having a ketone substituent at the C-13 or C-14 carbon atom are preferred as those linked to form improved drugs. Such C-13 linked bis-anthracycline compounds therefore generally have a structure such as the example that follows:



Since in such a formula it is necessary that the C-13 carbon atom formed a part of a functional ketone grouping, it will be noted that the Daunorubicin, Adriamycin and Carminomycin anthracyclines and their analogs are greatly preferred for use in forming the bis-compounds. It should be understood however that even those anthracyclines which do not have ketone substituents on the C-13 carbon atom can be converted into suitable bis-compounds through the C-14 atom or so long as the particular substituent on the C-13 carbon atom is converted either to a ketone grouping prior to the linking step or to a suitable moiety for linkage to carboxylic groups.

The linking group frequently contains an asymmetric carbon atom and both D and L isomers are discussed herein. Furthermore, portions of the anthracyclines such as saccharide substituents may within the invention have alpha, beta, or alpha/beta configurations.

While the bis-anthracyclines exhibit increased ability to interfere with DNA replication, their in vivo effectiveness can be even more greatly enhanced if the bis-anthracyclines are incorporated within liposomes before

ingestion. More specifically, the bis-anthracyclines may be encapsulated within liposome structures which comprise minute hollow spheres of lipid compounds. These liposome structures are known in the prior art and are prepared from various types of lipids such as phospholipids, cholesterols etc. It is known that various materials including drugs may be encapsulated within the liposome interiors and it has been found that incorporating the bis-anthracyclines within such structures provide increased effectiveness of the drug within the mammalian organism.

The present invention thus provides compounds which are bis-anthracyclines, that is to say compounds in which two anthracycline molecules have been linked together by a linking group chemically bonded to each of them. The invention also provides a method of producing these compounds.

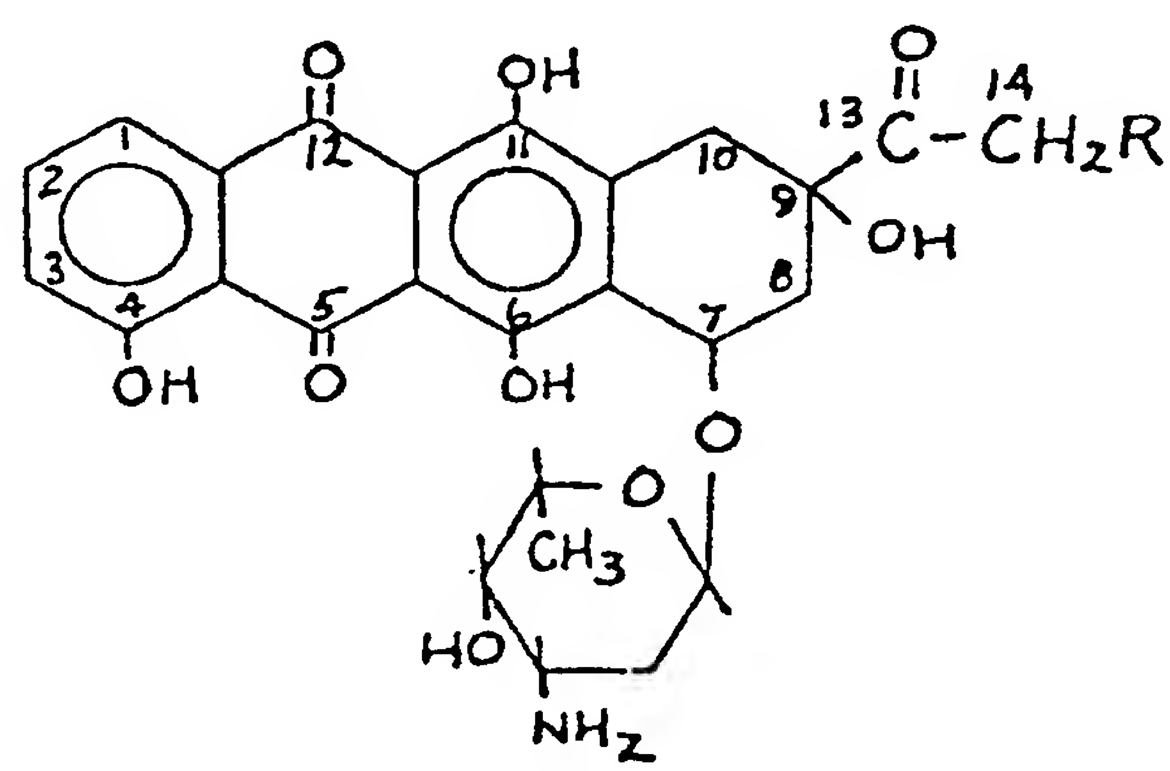
It should be understood that the term bis-anthracycline denotes a class of compounds characterised by the presence - linked together- of two anthracycline units, that is to say units having the skeletal structure which is characteristic of anthracyclines, and not limited to any particular specific substituents at specific positions.

As noted above, the bis-anthracyclines may, for effective delivery within the body to diseased sites, be incorporated into liposomes. The invention also provides a method, which is an extrusion method, for producing liposomes of uniform size.

Further description and explanation of the invention, and of examples, now follows.

The present invention contemplates new compositions of matter known as bis-anthracyclines. Bis-anthracyclines are two anthracycline moieties linked together with a bridge structure generally derived from hydroxy-or amino-dicarboxylic acids.

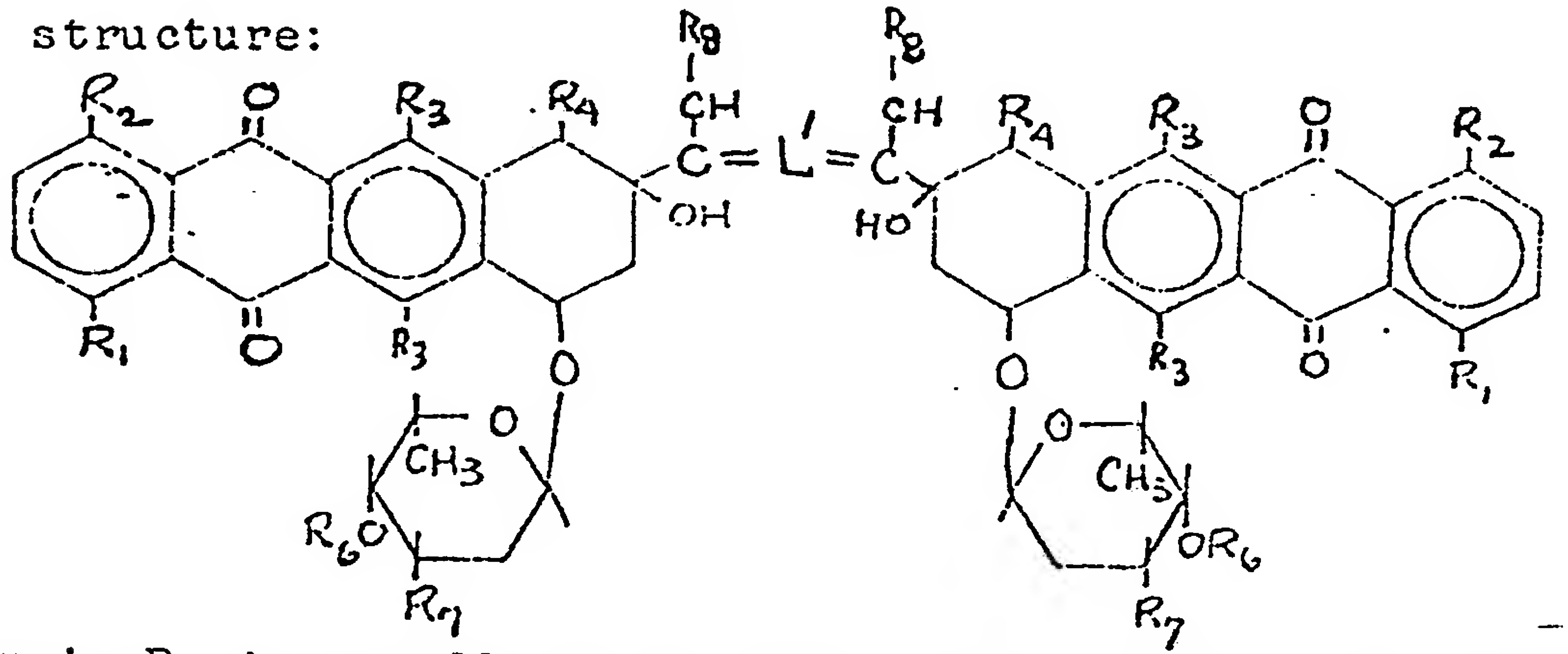
For purposes of the invention the anthracyclines are linked together at the C-13 carbon atom position. More specifically, a typical anthracycline molecule may be depicted as:



It should be noted that a ketone functional group, i.e., $-\overset{O}{\overset{\|}{C}}-CH_2R$ exists at the C-13 carbon position and R may be H, OH, O-alkyl, etc.

It has been determined that hydroxy- or amino-dicarboxylic acids will react with the C-13 carbon atoms to form a cross-linked bis-anthracycline compound. This reaction can occur under conditions sufficiently mild to leave the rest of the anthracycline molecule unchanged along with the usual characteristics thereof.

The bis-anthracyclines therefore generally have the structure:



wherein R_1 is usually OH or OCH_3; and R_2 and R_3 are usually -H, $-OH_2$ or $-OCH_3$; R_4 may range from -H to a carboxyl ester; R_6 may be -H or a mono- or di-saccharide; and R_7 is, most often, -OH or an amine or mono or di-alkylamine, and R_8 is -H, -OH or -O-ester.

L′ can be an hydroxy- or amino-dicarboxylic acid derivative. More specifically, L′ may be an amino-dicarboxylic acid dihydrazide:

$$NH_2\text{-}NH\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}\overset{\overset{\displaystyle NH_2}{|}}{CH}\text{-}(CH_2)_n\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}NH\text{-}NH_2$$

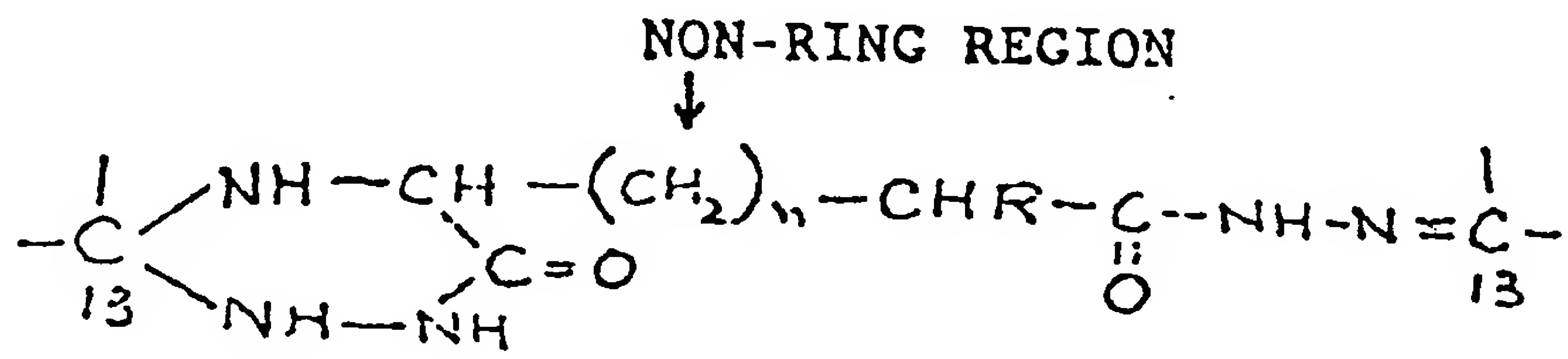
wherein n= 1 to 4; and the linking substituent then is:

$$-\underset{13}{\overset{|}{C}} = N\text{-}NH\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}\overset{\overset{\displaystyle NH_2}{|}}{CH}\text{-}(CH_2)_n\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}NH\text{-}N = \underset{13}{\overset{|}{C}}-$$

wherein the C-13 carbon at each end indicate the bis-linkage on two anthracycline molecules and the C-N may or may not be saturated or substituted.

In addition, amino-diesters may be utilized as a cross-linking agent. For instance $ROCOCH(NH_2)(CH_2)_nCOOR$ (wherein R is CH_3, $-C_2H_5$, etc.) may serve as a cross-linking agent. It is only necessary to react such esters with hydrazine prior to the linking step to convert them to the equivalent cross-linking agents previously noted.

In any event, the mono-anthracyclines may be cross-linked to form the bis-anthracyclines, either in acid medium or in basic medium. When reacted in acid medium, the straight chain linked bis-anthracyclines result. When reacted in neutral or basic medium, (or when the straight-chain product is further reacted in basic medium) the straight-chain linking substituent is converted to the cyclic structure:

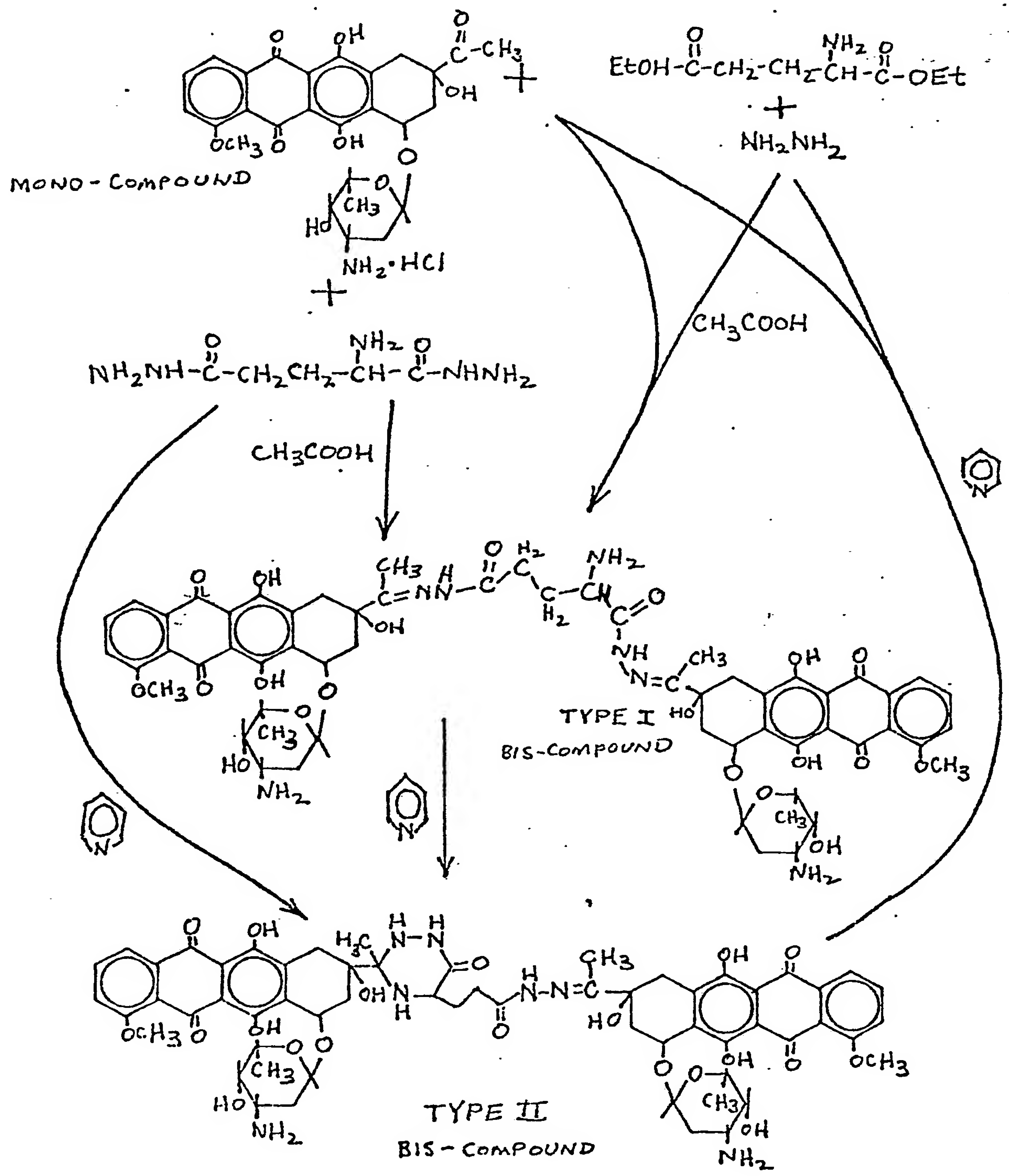


wherein R = H or any suitable moiety.

Some studies have indicated that the cyclic linked bis-anthracyclines may exhibit greater activity than their straight-chain counterparts. For example, they are over 10 times as potent as inhibitors of DNA directed transcription as the non-cyclic straight chain counterpart. For purposes of reference herein, the bis-anthracyclines having straight-chain linking will be referred to as Type I; while those having the cyclic linkage will be referred to as Type II.

A great variety of hydroxy- and amino-dicarboxylic acids (and esters) may be utilized as cross-linking agents. A number of such variations are noted in Tables 1, 1a and 1b herein below. However, other variations are possible and it is not intended to limit the linkage to those noted in Tables 1, 1a and 1b.

The preparation of the bis-anthracyclines from the mono-anthracyclines may be schematically noted as follows:



As noted above, to yield the straight-chain linked or Type I bis-anthracycline, the mono-anthracycline is reacted with the cross-linking agent in an acid medium, e.g., acetic acid. To yield the cyclic linked Type II bis-anthracycline, the mono-anthracycline is reacted in a neutral or basic medium, e.g., amines, pyridines, etc.

The type I product may also be converted to the Type II product by contacting the initial Type I product with a basic medium. Conversions to the Type II product take place almost completely.

Reaction conditions are extremely mild so that conversion to the bis-compounds does not degrade or affect the basic anthracycline structure. Particular care must be taken to protect the saccharide substitutents (R_6) that occur on many of the anthracyclines. In general, the cross-linking agent is reacted with the mono-anthracycline in a 1:2 molar ratio in an alcohol (MeOH) medium at about 25° C. If the Type I bis-compound is desired, a suitable acid, e.g., acetic, is added to the reaction mixture. If the Type II bis-compound is desired the reaction is conducted in neutral media or a suitable base, e.g., pyridine, is added.

The reaction is permitted to proceed slowly for a period of hours to days, its progress being followed by TLC and standard analysis techniques to determine the conversion of the mono-anthracycline to the bis-anthracycline. The bis-compound either precipitates from the reaction solution or is recovered therefrom by standard methods. Yields are in the 90% range.

The following examples demonstrate the preparation of the bis-anthracyclines. Both the preparation of Type I

straight-chain linked product and Type II cyclic linked product are illustrated.

In all instances, conversion to the bis-compound was monitered by thin layer chromatography (TLC) conducted on a pre-coated silica gel plate supplied by E. Merck (F-254, thickness 0.25 mm) utilizing a solvent system of $CHCl_3$-MeOH-AcOH-H_2O (80:20:14:6), and temperatures are given in °C.

EXAMPLE 1

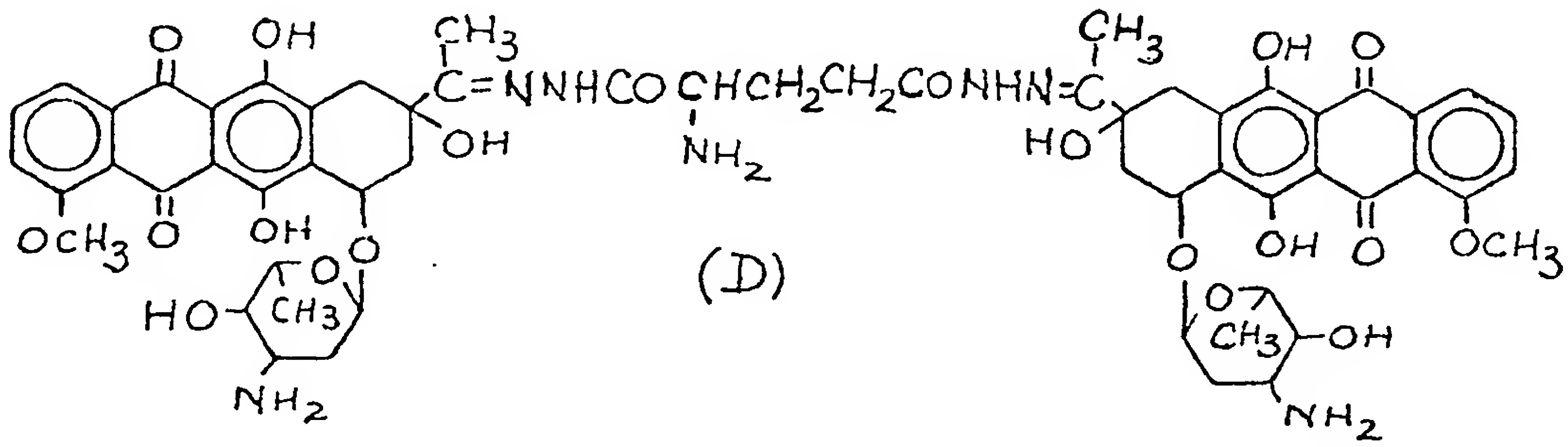
Bis-daunorubicin linked by D-glutamic dihydrazide

D-Glutamic dihydrazide was first prepared for use as the linking moiety by the following reaction:

$$\text{EtO-CO-}\overset{(D)}{\underset{\displaystyle NH_2}{CH}}\text{CH}_2\text{CH}_2\text{-COOEt} \xrightarrow{NH_2NH_2 \cdot H_2O} \text{H}_2\text{N-HN-CO-}\overset{(D)}{\underset{\displaystyle NH_2}{CH}}\text{CH}_2\text{CH}_2\text{CO-NH-NH}_2$$

To a solution of 1.015 g of diethyl D-glutamate in 5 ml of methanol was added a solution of 550 mg of hydrazine hydrate in 3 ml of methanol and the mixture was stirred at room temperature overnight. The reaction mixture was concentrated in vacuo and the residue was crystallized in a small amount of ethanol-ether. Recrystallization from methanol. Mp 150-151° (dec), $[\alpha]_D^{27}$ -27.2° (c0.5, H_2O).

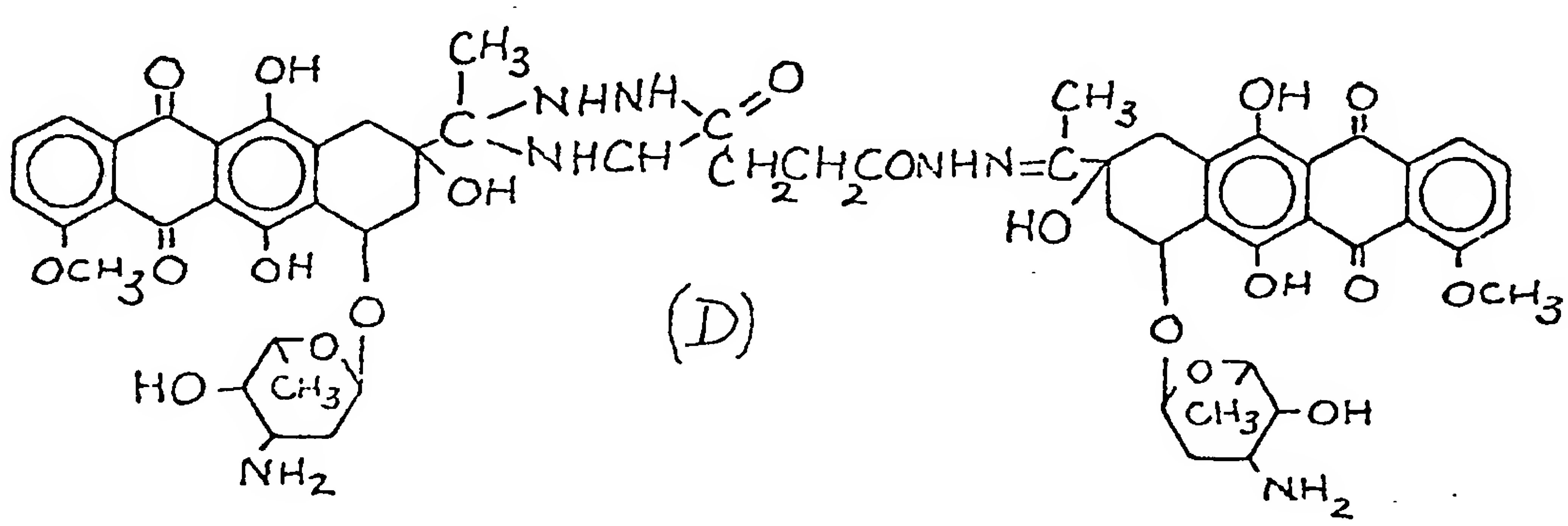
Bis-daunorubicin linked by straight chain of D-glutamic dihydrazide was prepared as per the following:



A solution of 56 mg (0.1 mmol) of daunorubicin hydrochloride and 9 mg (0.05 mmol) of D-glutamic dihydrazide in 5 ml of methanol and 0.3 ml of acetic acid was kept at room temperature overnight. To the solution was added a large volume of ether and the precipitates were collected by filtration. The precipitates were dissolved in 5 ml of methanol and 0.4 ml of 0.5N HCl-methanol and ether was added to the solution. The precipitates of the bis-daunorubicin hydrochloride were collected by filtration. Amorphous powder; yield 62 mg; mp 182^{o} (dec); TLC, Rf 0.05.

EXAMPLE 2

Bis-daunorubicin linked by cyclic chain of D-glutamic dihydrazide was prepared as follows:



A solution of 56 mg (0.1 mmol) of daunorubicin hydrochloride and 9 mg (0.05 mmol) of D-glutamic dihydrazide in 5 ml of methanol was stirred at room temperature for 9 days. Ether was added to the reaction mixture and the precipitates were collected by filtration. The precipitates were dissolved in 5 ml of methanol and 0.3 ml of acetic acid and then ether was added to the solution. The precipitates of the bis-daunorubicin acetate were collected by filtration. Amorphous powder; yield 60 mg; mp 192^{o} (dec); TLC,Rf 0.35.

EXAMPLE 3

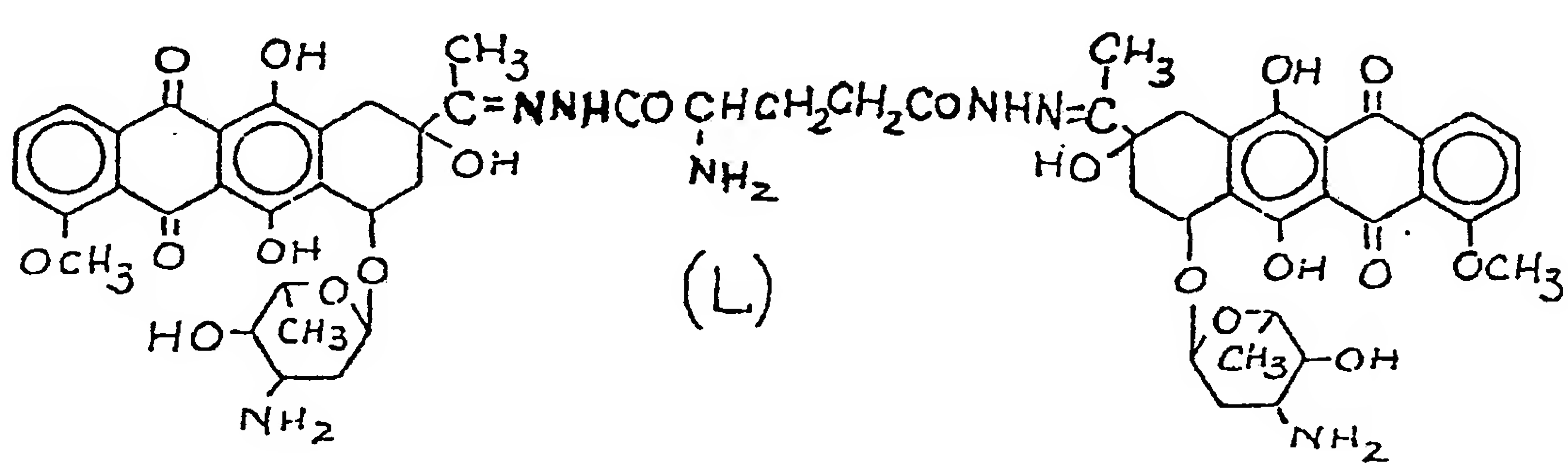
Bis-daunorubicin of L-glutamic dihydrazide was prepared as follows:

L-Glutamic dihydrazide preparation:

$$\underset{\displaystyle NH_2}{\overset{(L)}{EtO\text{-}COCHCH_2CH_2COOEt}} \xrightarrow{NH_2NH_2 \cdot H_2O} \underset{\displaystyle NH_2}{\overset{(L)}{H_2NHNCOCHCH_2CH_2CONHNH_2}}$$

The L-Glutamic dihydrazide was prepared by the same procedure as in the synthesis of D-glutamic dihydrazide. Mp 149-150^{o} (dec);$[\alpha]^{27}_{D}$ 26.0 (c0.5, H_2O).

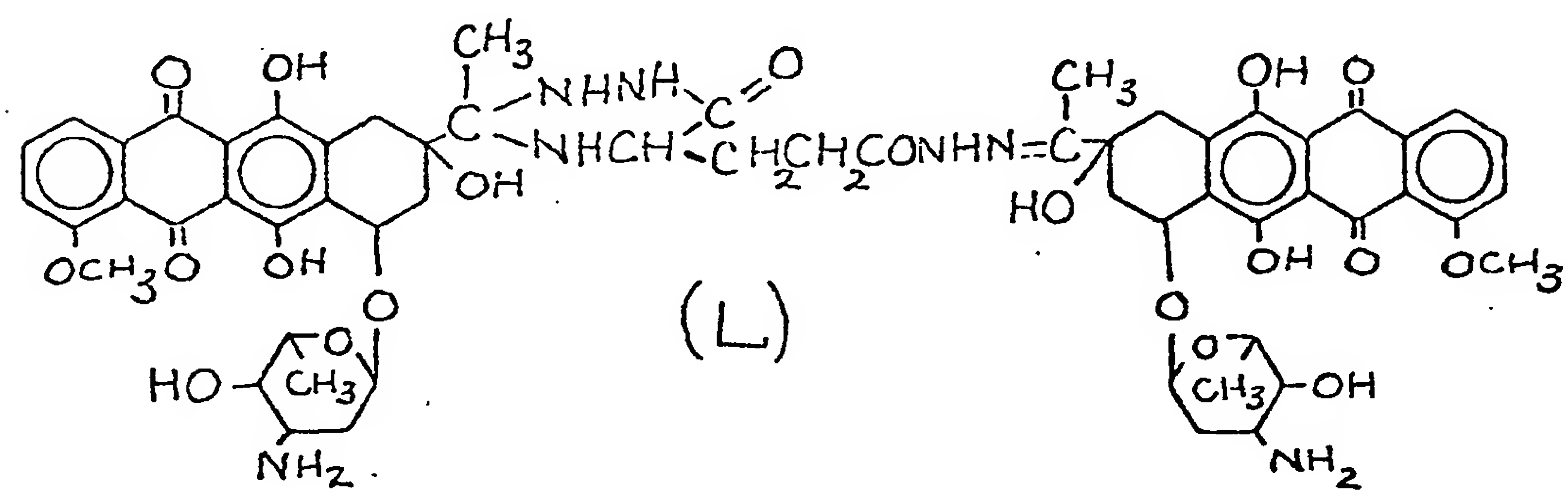
Bis-daunorubicin linked by straight chain of L-glutamic dihydrazide preparation.



A solution of 56 mg (0.1) mmol) of daunorubicin hydrochloride and 9 mg (0.05 mmol) of L-glutamic dihydrazide in 5 ml of methanol and 0.3 ml of acetic acid was maintained at room temperature overnight. To the reaction solution was added ether and the precipitates were collected by filtration. The precipitates were dissolved in 5 ml of methanol and 0.4 ml of 0.5N HCl-methanol.Ether was then added to the solution. The precipitates of the bis-daunorubicin hydrochloride were collected by filtration. Amorrphous powder; yield 62 mg; mp 179° (dec); TLC, Rf 0.05.

EXAMPLE 4

Bis-daunorubicin linked by cyclic chain of L-glutamic dihydrazide



(L)

A mixture of 56 mg (0.1 mmol) of daunorubicin hydrochloride and 9 mg (0.05 mmol) of L-glutamic dihydrazide in 5 ml of methanol was stirred at room temperature for 9 days. To the reaction solution was added ether and the precipitates were collected by filtration. The precipitates were dissolved in 5 ml of methanol and 0.3 ml of acetic acid. Ether was then added to the solution. The precipitates of the bis-daunorubicin acetate were collected by filtration. Amorphous powder; yield 60 mg; mp 192° (dec); TLC, Rf 0.35.

EXAMPLE 5

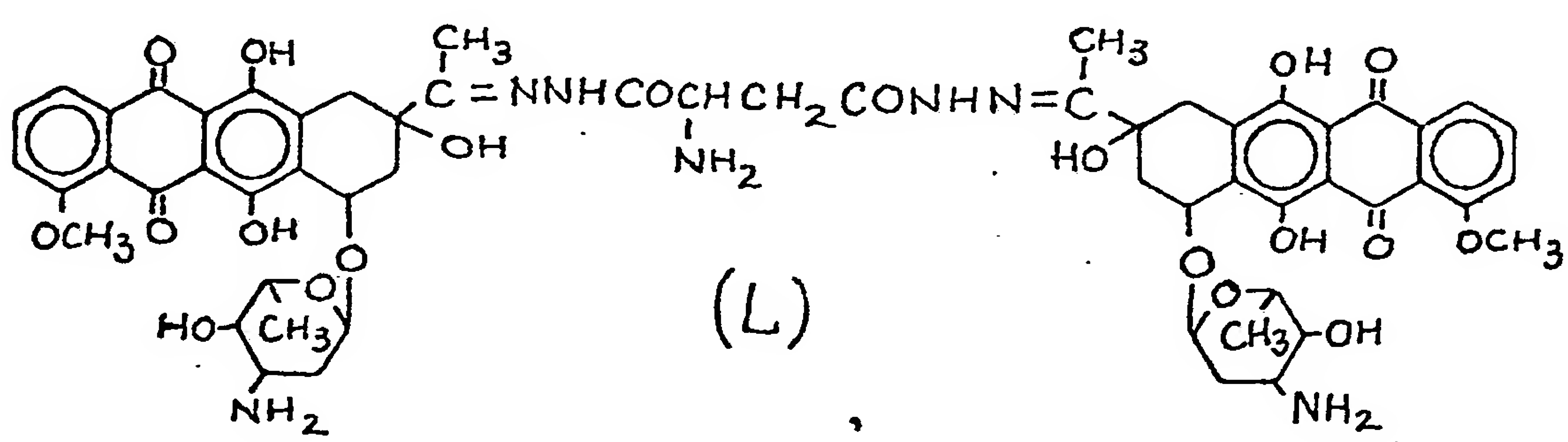
Bis-daunorubicin of L-aspartic dihydrazide preparation.

L-Aspartic dihydrazide was first prepared.

$$\underset{\displaystyle\quad\;\; NH_2}{EtO\text{-}CO\overset{|}{C}HCH_2COOEt} \xrightarrow{NH_2NH_2 \cdot H_2O} \underset{\displaystyle\qquad\quad NH_2}{H_2NHN\text{-}CO\overset{|}{C}HCH_2CO\text{-}NHNH_2}$$

L-Aspartic dihydrazide was prepared by the same procedure as for the synthesis of D-glutamic dihydrazide noted above. Recrystallization took place from aqueous ethanol. Mp 165-167° (dec).

Bis-daunorubicin linked by straight chain of L-aspartic dihydrazide preparation.

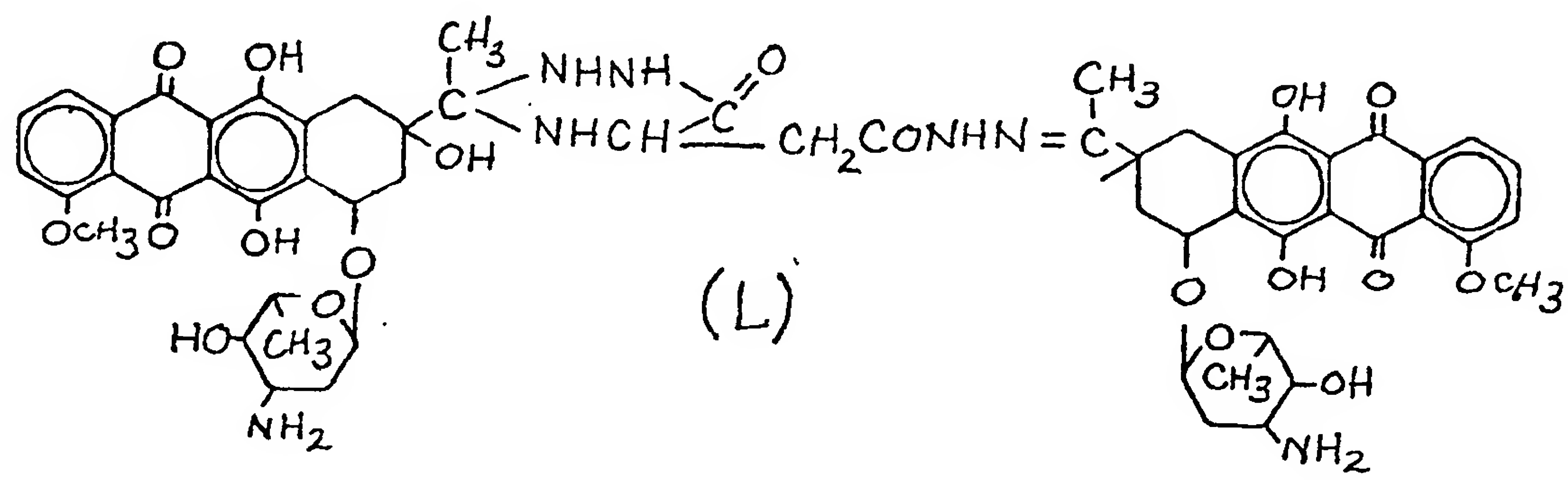


A solution of 56 mg (0.1 mmol) of daunorubicin hydrochloride and 8 mg (0.05 mmol) of L-aspartic dihydrazide in 5 ml of methanol and 0.3 ml of acetic acid was maintained at room temperature overnight. To the reaction solution was added ether and the precipitates were collected by filtration. The precipitates were dissolved in 5 ml of methanol and 0.4 ml of 0.5N HCl-methanol. Ether was then added to the solution. The precipitates of the bis-daunorubicin hydrochloride were collected by filtration.

Amorphous powder; yield 60 mg; mp 190° (dec); TLC, Rf 0.04.

EXAMPLE 6

Bis-daunorubicin linked by cyclic chain of L-aspartic dihydrazide preparation.

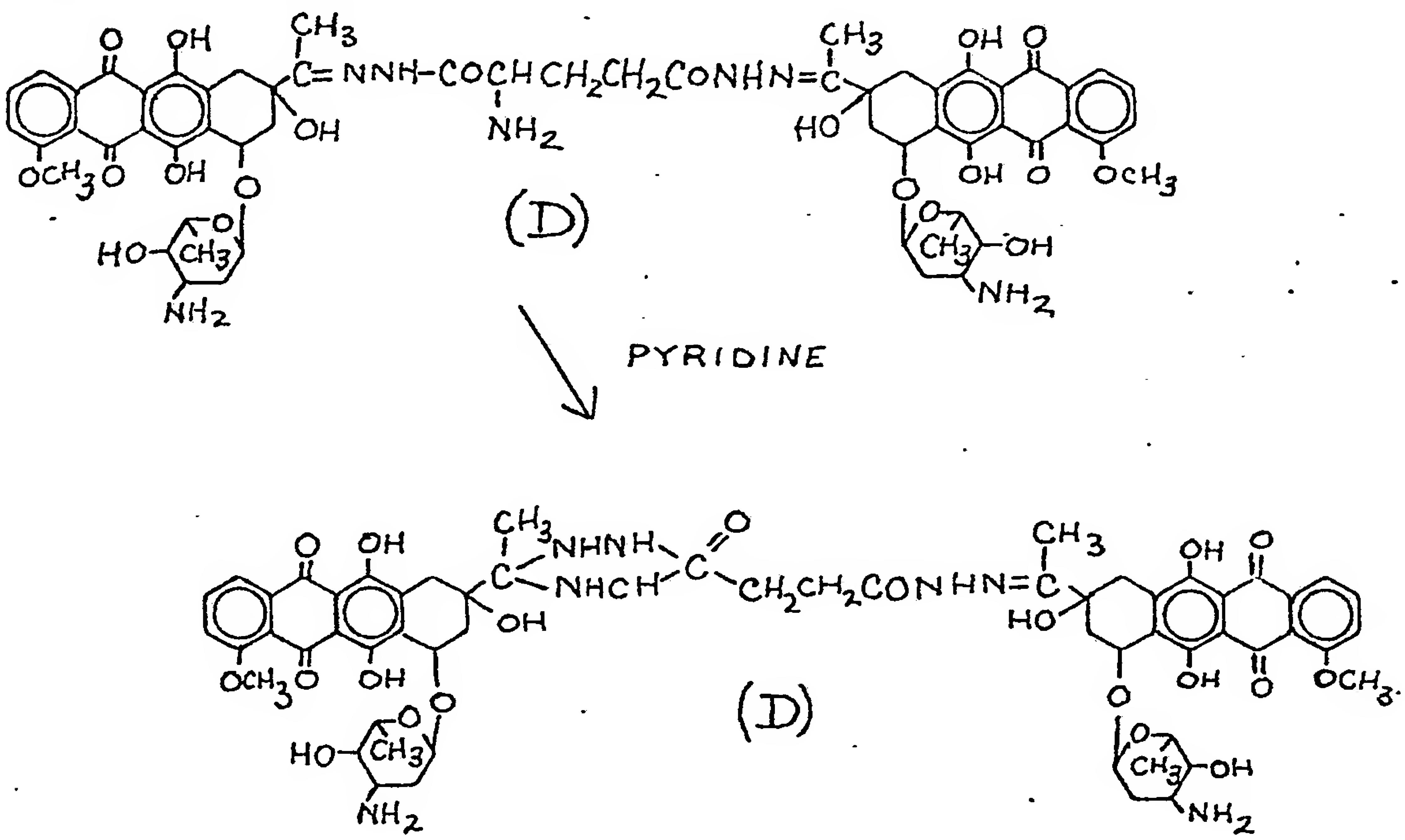


(L)

A mixture of 56 mg (0.1 mmol) of daunorubicin hydrochloride and 8 mg (0.05 mmol) of L-aspartic dihydrazide in 5 ml of methanol was stirred at room temperature for 9 days. To the reaction mixture was added ether and the precipitates were collected by filtration. The precipitates were dissolved in 5 ml of methanol and 0.3 ml of acetic acid. Ether was then added to the solution. The precipitates of the bis-daunorubicin acetate were collected by filtration. Amorphous powder; yield 59 mg; mp 195° (dec); TLC, Rf 0.35.

EXAMPLE 7

Conversion of straight chained bis-daunorubicin of D-glutamic dihydrazide to cyclic chained bis-daunorubicin



A solution of 20 mg of bis-daunorubicin linked by straight chain D-glutamic dihydrazide and 0.1 ml of pyridine in 3 ml of methanol was kept at room temperature for 7 days. Ether was added and the precipitates were collected by filtration. The precipitates were dissolved in 2 ml of methanol and 0.2 ml of acetic acid. Addition of ether gave the precipitates of the bis-daunorubicin linked by a cyclic chain of D-glutamic dihydrazide. Yield 15 mg.

Other bis-daunorubicins linked by straight chain moieties were prepared using the methods of the invention as noted above. These bis-daunorubicins and their activities are set forth in Table 6 below.

In any event, the crystallized bis-anthracyclines are recovered and kept refrigerated and protected from light until use. There is some tendency for some of the bis-

compounds to very slowly degrade with time in solution and it is therefore advisable to use them as soon as possible unless they are stored as an anhydrous powder or protected as noted.

THE LIPOSOMES

Liposomes are lipid micro- vesicles of approximately spherical shape. The outer shell of a liposome consists of a phospholipid bilayer which encloses a volume of water, an aqueous solution or partly aqueous solution. Liposomes with only one lipid shell are designated unilamellar vesicles; those with additional lipid shells, like layers of an onion, are called multilamellar vesicles. Either type may be small, e.g., 150-400 nm in diameter, or large, e.g., up to the size of red blood cells. A large liposome may contain many times the volume of a small liposome.

Liposomes may be produced by hydration and mechanical dispersion of dried lipoidal material in an aqueous solution. The lipoidal material can be phospholipids or other lipids, cholesterol and its derivatives or a variety of amphiphiles including macromolecules or mixtures of these. However, liposomes prepared this way are mixtures of all the types noted above, with a variety of dimensions, compositions and behaviors. This unpredictable variety leads to inconsistent measures of liposome properties and unreliable characterizations. To reduce the heterogeneity of mechanically dispersed liposomes, such dispersions may be exposed to sonication which decreases average liposome size. Under extensive sonication, occasionally populations of liposomes are reduced to small

unilamellar vesicles, but the sonic process does not give homogeneous dispersions of larger vesicles and can degrade the complex lipids and other components of the liposomes.

The preparation of liposomes and their use in drug therapy has been previously described. See, for instance, U.S. Patent 4,053,585; German Patent 2,532,317; Netherlands application 73/04133; and Biochemistry 16(12)2806(1977).

The present invention utilizes a process for producing liposomes of uniform size and composition; and with predictable properties. Such process utilizes extrusion as the final step during the production of the liposomes. The extrusion step may be repeated a number of times to further refine the liposomes with respect to decreasing their size and maximizing uniformity in size.

According to the invention the liposomes, in which the bis-anthracyclines are encapsulated are produced as follows:

Those agents which are to compose the lipid membrane of the liposome, such as phospholipids, cholesterol and/or other biologically active or inactive amphiphiles, or macromolecules are mixed in an organic solvent such as ethers, chloroform, alcohol, etc. and then dried onto the interior surface of a vessel under a vacuum. As an example,

phosphatidic acid, L-alpha-lecithin and cholesterol were mixed into a chloroform: isopropanol: methanol::7:3:1 solution and vacuum dried. An aqueous solution of the drug was added to the dried lipids at a temperature above the phase transition temperature of the lipid mixture. In this example, a bis-anthracycline at 1 mg/ml in isotonic phosphate buffer was added and the solution rolled with the lipids for one hour to allow slow hydration.

The resulting liposome size was greater than 0.5 micron in diameter (light scattering method).These mechanically dispersed liposomes are then passed through a Nuclear-Pore type filter (uniform pore size) starting with 1.00 micron and going successively down to the desired vesicle size (e.g. 0.1 micron). If the lipid concentration of these mechanically dispersed liposomes was greater than 10 mgm/ml the process was repeated for maximum uniformity. Following these steps the untrapped drug was removed from the vesicles by dialysis and the drug-containing vesicles were collected for further use.

If the liposome size is desired to be less than, 0.1 to 0.05 micron, the mechanically dispersed liposomes are then extruded under high pressure through a small orifice. For example, the mechanically dispersed liposomes were extruded using a French Press and Pressure Cell (Aminco type) maintained at about 25 bar during the entire extrusion. The extrusion may be repeated for

enhanced uniformity of liposome. The extrusion pressure, orifice size, and temperature can be used to control the size of the resulting vesicles and very uniform liposomes can be easily and reproducibly made by this process. Extrusion may be at pressures up to 43.5 bar.

Subsequent to the extrusion, the free untrapped drug can be removed readily by dialysis leaving a uniform, stable liposome population containing the drug.

As noted the liposome wall material may be any desired lipid, such as phospholipids, cholesterol, etc. Such liposomes may be produced, as noted, in closely controlled sizes; and, in addition depending on the lipid employed, with positive or negative charges thereon.

Utilizing controlled liposome size, material and charge, it has been determined that in the mammalian organism, the liposomes will preferably collect in particular organs, such as lung, liver, spleen, etc. Thus, the encapsulated drug may be delivered to specific sites within the organism. It will be apparent that utilization of the liposomes for such purposes, facilitates the effectiveness of the drug in contacting tissues at selected

sites since the drug will concentrate at the selected sites. At the same time, the drug concentration throughout the general body tissues will be greatly lowered to reduce undesirable side effects.

INHIBITION OF DNA REPLICATION

Some bis-anthracyclines of the invention were tested for effectiveness in interfering with DNA replication or transcription reactions. For comparison, the clinically useful anthracycline Daunorubicin was used as the control and the bis-anthracyclines were prepared from the Daunorubicin monomolecules, utilizing various amino-dicarbocylic acid linking agents. All of the bis-anthracyclines were produced under acid conditions to yield the Type I bis-anthracyline products as previously noted.

Drugs which bind to DNA as a receptor can inhibit a variety of replication or transcription reactions. One index of activity is the I_{50} or concentratuon of drug in millimicromoles/milliliter in vitro needed to inhibit a nucleic acid-dependent function (the lower the I_{50} the higher the activity of the drug). Tables 1, 1a and 1b compare the activities of representative samples of bis-anthracylines as inhibitors of RNA-directed-DNA polymerase (Assple, Ann. Rep.Med.Chem.8:251,1973, described the assay method used to determine activities, I_{50}).

Table I

EFFECT OF BIS-ANTHRACYCLINES ON DNA TRANSCRIPTION IN VITRO

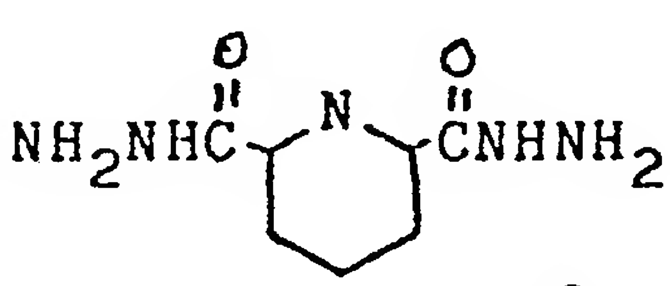
LINKAGE GROUP	TYPE I PRODUCT mp C	I_{50}
1. DAUNORUBICIN (control mono drug)	–	105
2. $NH_2NH\overset{\overset{O}{\|}}{C}CH_2\overset{\overset{OH}{|}}{C}HCH_2\overset{\overset{O}{\|}}{C}NHNH_2$	189	15
3. $NH_2NH\overset{\overset{O}{\|}}{C}CH_2\overset{\overset{NH_2}{|}}{C}HCH_2\overset{\overset{O}{\|}}{C}NHNH_2$	182	10
4. $NH_2NH\overset{\overset{O}{\|}}{C}CH_2\overset{\overset{NH_2}{|}}{C}H\overset{\overset{O}{\|}}{C}NHNH_2$	190	10
5. $NH_2NH\overset{\overset{O}{\|}}{C}CH_2NHCH_2\overset{\overset{O}{\|}}{C}NHNH_2$	185	20
6. 	220	8
7. $NH_2NH\overset{\overset{O}{\|}}{C}CHOHCHOH\overset{\overset{O}{\|}}{C}NHNH_2$	164	11
8. $NH_2NH\overset{\overset{O}{\|}}{C}CHNH_2(CH_2)_3CHNH_2\overset{\overset{O}{\|}}{C}NHNH_2$	190	5

Table 1a

ACTIVITY OF TYPE I BIS-ANTHRACYCLINES ON REVERSE TRANSCRIPTION (RSV) RNA DEPENDANT DNA POLYMERASE.

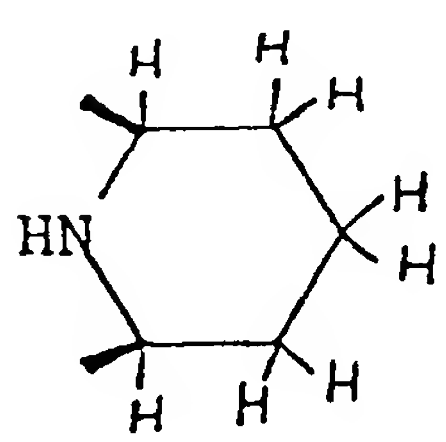
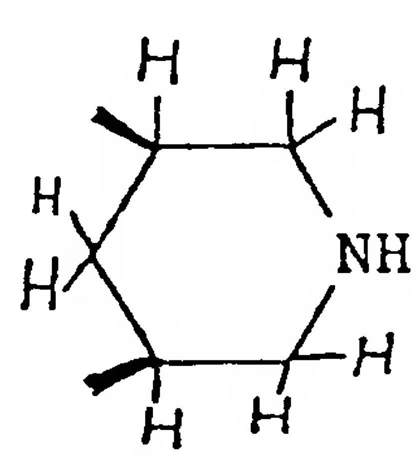
	Linkage (only the asymmetrical portion of the linkage is noted)	MP °C(dec) (HCl salt)	TLC Rf	I50 µm/1
Daunorubicin (control)			0.59	105
1	CH_2CH_2	158	0.22	52
2	$CH_2CH(OH)CH_2$	189	0.14	15
3	$CH_2CH(NH_2)CH_2$	182	0.05	10
4	$CH(NH_2)$	184	0.05	7.5
5	$CH(NH_2)CH_2$ (L)	190	0.04	10
6	$CH(NH_2)CH_2$ (DL)	180	0.04	7.5
7	$CH(NH_2)CH_2CH_2$ (L)	179	0.05	7.5
8	$CH(NH_2)CH_2CH_2$ (D)	182	0.05	7
9	$CH(NH_2)(CH_2)_3(CH(NH_2)$ (DL)	190	0.00	5.5
10	$CHNHCH_2$	185	0.03	20
11		220	0.07	8
12		183	0.05	8
13	CH(OH)CH(OH (D)	164	0.12	11
14	CH(OH)CH(OH) (L)	164	0.12	9.5

Table 1b

ACTIVITY OF TYPE II BIS-ANTHRACYCLINES ON RSV RNA DEPENDENT DNA POLYMERASE.

	Linkage (only the non-ring portion of the linkage is noted)	MP °C(dec) (acetate salt)	TLC Rf	I_{50} µm/1
1	CH_2 (L)	195	0.35	3
2	CH_2CH_2 (L)	195	0.35	2.5
3	CH_2CH_2 (D)	192	0.35	2.5

From the above data, it is quite apparent that the bis-anthracyclines have tremendously enhanced ability to interfere with DNA replication as compared to one of the most highly active anthracyclines.

Activity of Straight Chain and Ring Linked Bis-anthracyclines

It appears that bis-anthracyclines produced in basic medium (Type II) are generally more potent than the corresponding bis-anthracyclines produced in acid medium (Type I), and that depending on the individual linkage group employed, either the D- or the L- isomer may be more

activity as a drug, or they may be similar. Table 2 below presents a comparison:

TABLE 2

COMPARISON OF D/L AND FREE/RING SOUND AMINO LINKAGE GROUPS USING AMINO-DICARBOXYLIC ACID LINKAGE UNIT OF $H_2NNH-\overset{O}{\overset{\|}{C}}-CH(NH_2)(CH_2)_2-\overset{O}{\overset{\|}{C}}-NHNH_2$

	TYPE I		TYPE II		
isomer	mp(HClO ^{o}C	I_{50}	mp(HCl) ^{o}C	I_{50}	
L-	179	8	195	2	
D-	182	7	192	<1	(a) see Table 3

Daunorubicin - Control 150

Table 2 tends to indicate that both the D- and L-forms of the bis-anthracylines are similarly active as inhibitors of DNA transcription, but that the Type II compounds are significantly more active by almost an order of magnitude than the Type I compounds.

A study of the effectiveness of Type 1 and Type II bis-anthracyclines in vivo as anti-cander drug was also undertaken. Using a standard set of conditions such as that used by the National Cancer Institute, BDF_1 or CDF_1 mice with implanted P388 Leukemia will usually succumb of cancer in 10-12 days. Drugs with clinical potential as cancer chemotherapeutics and used from Day 1 (day after leukemia implant) through Day 9 will extend the lifespan of these mice by 25% or more. Drugs which extend the life of these mice by 50+% are often superior, and drugs which extend the mouse lifespan under these conditions by 100+% are exceptional. Occasionally, a more advanced disease model is used, in which the drug is given Q4D-5,9,13. In this model ("advanced P388") the first drug injection is delayed until 5-6 days before the expected death of the leukemic animal.

The degree of effect is much less and many useful drugs which would pass the 25% increase in lifespan test when treatment is started on Day 1 would not show any effect on the advanced P388 leukemia treatment schedule. While it is more rigorous, some drugs do manage a 25+% increase in lifespan in the advanced P388. Many drugs clinically useful in cancer do not do this well in the advanced P388. The results indicate that the bis-anthracyclines herein are significantly active in the advanced P388 model. Table 3 shows these results:

Table 3

IN VIVO EFFECT OF BIS-ANTHRACYCLINES IN ADVANCED P388 LEUKEMIA

COMPOUND HCl salt		% INCREASED LIFESPAN (Starting day 1)	% INCREASED LIFESPAN advanced P388
Daunorubicin	1	65%	30%
Table 1 Compound #	3	105%	40%
	7	-	50%
	6	-	55%
	8*	-	85%
Table 2 Compound (a)		-	50%

(*the acetate salt of compound 8 gave 50+% increased lifespan in advanced P338)

Enhanced effectiveness of Bis-anthracyclines in Liposomes vs free bis-anthracyclines.

The new bis-anthracyclines are generally more effective against mouse cancer than the parent mono-anthracycline, such as Daunorubicin, and effective clinical mono-anthracycline (see Table 2). On the other hand, the bis-anthracyclines were less potent and less effective than would be expected when extrapolated from the comparison in Table 2 in which the bis-anthracycline was over 100 times as potent as Daunorubicin. If this discrepancy is as due to the lower transport of the very large bis-anthracycline molecule into cells or to the target cellular receptor, then overcoming this possible barrier should enhance the drug effectiveness of bis-anthracyclines.

Daunorubicin and Type I and/or Type II bis-anthracyclines were encapsulated in liposomes of the small unilamellar class, composed of phosphatidic acid, L-alpha lecithins, and cholesterol. These uniform small unilamellar vesicles were prepared by a final step of extrusion from a French Press at a pressure of 25 bar.

The liposome encapsulated Tupe II bis-anthracycline drugs and free drugs were compared for their capacity to kill leukemic cells. The free drugs were about equally

active and equally potent when Daunorubicin and the bis-anthracyclines (the D-isomer of the compound cited on page 15) were compared for their cell kill of L1210 leukemia cells. Daunorubicin was found to change only a few % (not significantly) between acting as a free drug or being liposome encapsulated (the I_{50} was about 0.20 micromolar in both cases. However, the encapsulated bis-anthracycline (the D-isomer of the compound cited on Table 2) was very much improved in antileukemic activity when liposome encapsulated as noted in Table 4:

Table 4

IMPROVED ACTIVITY OF LIPOSOME ENCAPSULATED BIS-ANTHRACYCLINES

STATE	I_{50} LEUKEMIC CELL KILL
Free Drug	0.250 micromolar
Liposome encapsulated	0.003 micromolar

In addition, Daunorubicin or bis-daunorubicin incorporated into these same liposomes and administered into BDF_1 mice carrying P-388 leukemia, could be given at more than 2 times the lethal dose of the free drug without producing a lethal effect. Under these conditions they were still effective anti-leukemic drugs in vivo, showing that such encapsulation produced a therapeutic advantage in making the doses less toxic. Whereas the therapeutically effective injected dose of the Type II

bis-anthracyclines in treating murine leukemia may be 10-50 mg/kg on a q 4 d schedule, when the bis-anthracycline is incorporated into these same phosphatidic acid-lecithins- cholesterol liposomes, it is 2 to 8 mg/kg or 5 fold less. Thus it has been observed that the same liposome that lowers the risk of anthracycline toxicity can enhance the potency of the bis-anthracylines. The combination of these effects, increasing the dose needed to produce toxicity and increasing potency or lowering the dose required to achieve a therapeutically useful effect in treating in vivo murine leukemia, is called enhancing the therapeutic index of a drug. We have thus seen that incorporation into liposomes enhances or improves the therapeutic index of both mono anthracyclines, such as those now used for treating human diseases, and the new bis-anthracylines.

The bis-anthracylines as disclosed above may be administered for therapeutic purposes in any of the commonly acceptable forms. The addition salts are especially useful. The hydrochloride, sulfate, acetate, phosphate, maleate forms are all producable. For the Type I and Type II compounds listed hereinbefore, all these salts are active as drugs in mice; but the organic acid salts were often less active than

inorganic acid salts. However, other physiologically acceptable salts and variations thereof are contemplated for use herein. It is only necessary to ensure that any of the various forms of the compounds are acceptable from the pharmacological standpoint.

The bis-anthracyclines, whether in original or salt form, alone or encapsulated in liposomes, are introduced into the organism by any previously known method. When incorporated into liposomes, the drugs may be administered by intravenous or intraperitoneal injection, or orally, if desired. When administered without the liposomes, oral introduction is precluded, as the digestive process will destroy the drug before it can cross the intestinal membranes. Thus the drugs, in this instance, may be administered by injection. However, administration of the above noted drugs orally in effective doses, due to their incorporation into liposomes, offers a decided advantage over the requirement for drug injection with all its attendant risks and discomforts.

Directing drugs to specific or selective tissues in the mammalian species through incorporation in liposomes has been demonstrated. Table 5 below presents data in this regard and illustrates the effect of liposome size upon concentration in various tissues.

TABLE 5

% Dose[a] in Selected Tissues at Various Times after IV Administration of Size I and Size II[b] Liposomes to Mice

TIME	TISSUE					
	LIVER		SPLEEN		LUNG	
HOURS	Size I	Size II	Size I	Size II	Size I	Size II
after 1	19.8	24.1	4.5	5.0	$\boxed{8.5}$	1.0
after 5	8.3	$\boxed{20.5}$	2.9	2.7	$\boxed{5.7}$	0.5
after 24	0.5	0.7	0.3	0.3	$\boxed{5.2}$	0.1

a. The drug used was cytosine arabinoside. The liposomes in both cases were composed of phosphatidyl choline, phosphatidyl serine, and cholesterol in the ratio 5:1:5.

b. Size I was extruded to yield approximately 1.2 micron liposomes. Size II was extruded to yield approximately 0.5 micron liposomes.

Table 5 shows that size I liposomes accumulate in lung tissue; whereas no difference with respect to spleen tissue is noted. At early times, size II liposomes, on the other hand, preferentially accumulate in liver tissue.

Reaction With DNA

Measurements have been made with respect to the bis-anthracyclines' ability to react with DNA. Receptor dissociation time has been measured by stopped flow spectrophotometry. Such measurements indicate that mono-anthracyclines dissociate from double-stranded DNA in substantially under one second; however bis-anthracyclines dissociation times from double-stranded DNA is 20 to 100 fold longer.

CLAIMS:

1. A method for the production of liposomes of uniform size comprising forming liposomes in relatively random sizes, and then forcing the random sized liposomes through an orifice at high pressure to selectively force said liposomes into a uniform size.

2. The method of claim 1 wherein the liposomes are forced through the orifice at pressures up to about 43.5 bar.

3. The method of claim 1 or claim 2 wherein said liposomes are composed of lipids including phospholipids, macromolecules cholesterols, amphiphiles, or mixtures thereof.

4. A liposome made by the method of claim 1 claim 2 or claim 3 and incorporating a bis-anthracycline as claimed in European Patent Application publication No. 0 004 467.

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European Patent Office

EUROPEAN SEARCH REPORT

Application number
EP 81 20 0162

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
	FR - A - 2 298 318 (TANABE SEIYAKU) * Page 1, lines 1-5; page 2, line 5 to page 4, line 12; claims 1-3 * & US - A - 4 016 100 & GB - A - 1 487 989 ---	1-3
	PHARM. ACTA HELVETIA, vol. 52, no. 12, 1977, F. PUISIEUX et al.: "Les Liposomes, vêhicules possibles de principes actifs", pages 305-318 * Page 307, paragraph 2 (2.1); page 308, paragraph 2.2.1, "Methode par Baugham", "Methode de Batzri et Korn"; page 309, "Ultracentrifugation", "Liposomes d'actinomycine D"; page 310, "Capacité d'encapsulation"; page 316, "Traitement anticancéreux" * ---	1-4
	US - A - 3 993 754 (RAHMAN) * Column 1, lines 22-26; column 1, lines 45-59; column 2, lines 6-23; column 2, lines 45-65; column 3, lines 5-17; claims 1-3 * ---	1,3,4
	REMINGTON'S PHARMACEUTICAL SCIENCES, 14th edition, 1970, (Mack Publishing Company), EATON (US) * Page 326, "Ultrafiltration"; page 327; figure 203 * ---	1,2
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CLASSIFICATION OF THE APPLICATION (Int. Cl.3)

A 61 K 9/50
A 61 K 31/70
C 07 H 15/24

TECHNICAL FIELDS SEARCHED (Int. Cl.3)

A 61 K 9/50

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	26.06.1981	CONTET

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Application number

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- 2 -

European Patent Office

EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.3)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	AU - A - 53107/73 (LEUZINGER) * Page 1, line 1 to page 4, line 6; page 4, lines 23-30; claims 1, 4-7, 18 and 20 * ---	1,3	
P	CHEMICAL ABSTRACTS, vol. 88, no. 26, June 26, 1978, abstract 197528z, page 395, COLUMBUS, OHIO (US) RUDY L. JULIANO et al.: "Pharmacokinetics of liposome-encapsulated antitumor drugs. Studies with vinblastine, actinomycin D. cytosine arabinoside, and daunomycin" & Biochem. Pharmacol. 1978, 27(1), 21-7 * The whole article * ---	1,4	TECHNICAL FIELDS SEARCHED (Int. Cl.3)
P	DE - A - 2 656 333 (THEURER) * Page 1, lines 1-14; page 6, example 1, lines 1-23 * ---	1-4	
A	THE MERCK INDEX, 9th Edition, 1976, Merck & Co. Inc., RAYWAY (US) * No. 2815: "Daunorubicin" * ----------	4	